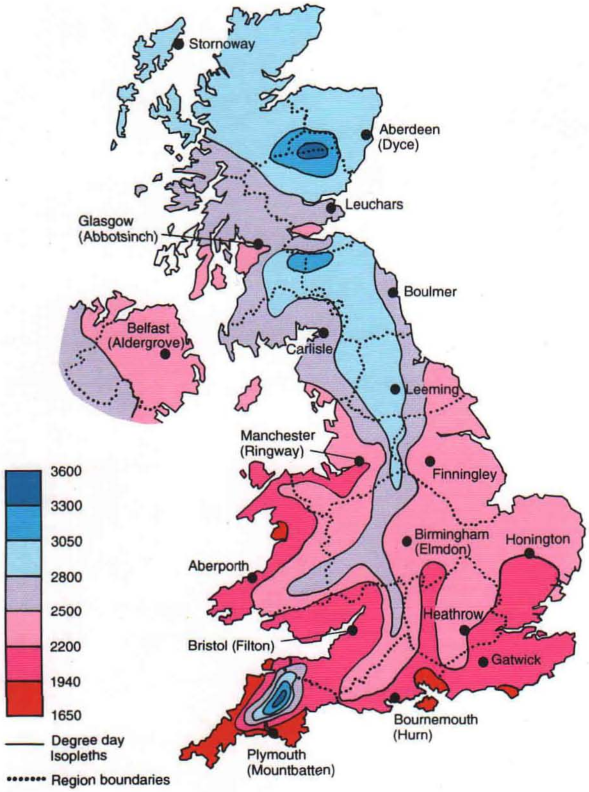
Degree Days



BEST PRACTICE PROGRAMME

Energy Efficiency Office

DEPARTMENT OF THE ENVIRONMENT

Degree Days

The views and judgements expressed in this Fuel Efficiency Booklet are not necessarily those of the Department of the Environment, the Energy Efficiency Office, ETSU or BRECSU.

Contents

1. Introduction

Degree days are a measure of the variation of outside temperature which enables building designers and users to determine how the energy consumption of a building is related to the weather.

Degree days are not a new idea. The original concept was put forward about 100 years ago for use in horticulture. Nowadays, however, by far the largest use of degree days is for building heating purposes, for which they have been used in Britain for about 50 years. Degree days have become especially important since it has been shown how valuable they are in monitoring the benefits of energy saving measures in buildings, particularly now that the very large amounts of energy that could be saved in buildings have been recognised.

2. What are degree days?

When the temperature maintained inside is higher than the temperature outside, any building will spontaneously lose heat. Making up this loss is the principal reason for having to supply heat to the building. Heat loss occurs by two main mechanisms:

- by conduction through the fabric of walls, floors, ceilings, roofs, door panels and window panes;
- by air moving through the building, entering and leaving through windows, doors, gaps, cracks and ventilators.

Since heat losses through the walls or ceilings of a heated building occur by conduction, the rate of heat loss is directly proportional to the temperature difference between the inside and outside of the building. Likewise, losses through air movement are due to heating ambient air entering the building at the outside temperature to the control temperature, with the amount of heating also corresponding to the temperature difference between inside and outside. This temperature difference is seldom constant but subject to continuous variation because, even though the inside temperature can be fixed, the outside temperature varies in an uncontrollable way.

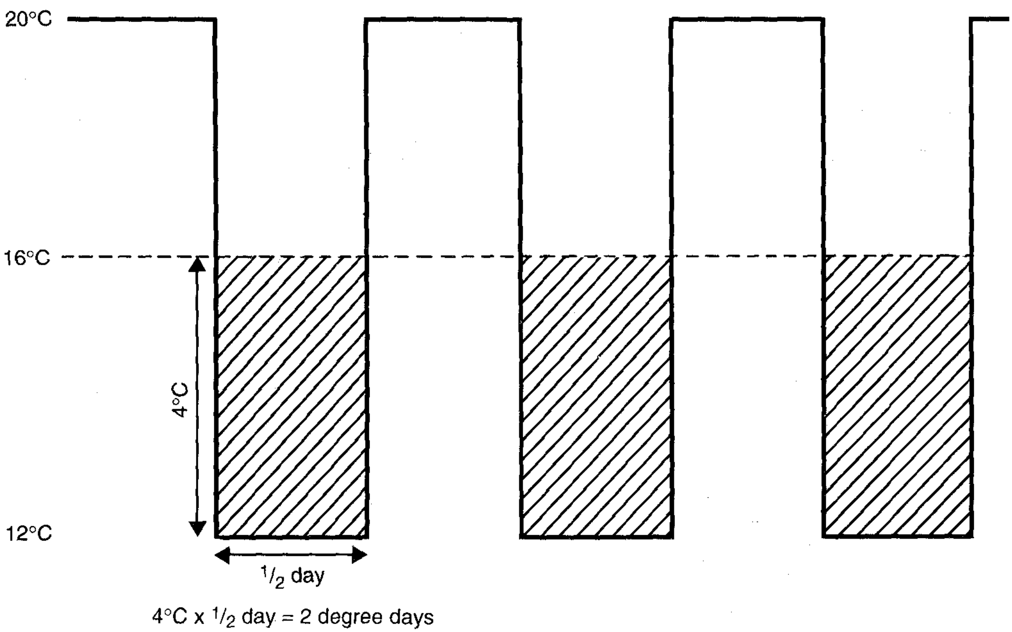


Fig 1 The relationship of degree days to average temperature

It is important to recognise that only rarely is the difference between the inside and *average* outside temperature in any way a reliable indicator of building heating needs.

This point is easily demonstrated. Fig 1 shows a simplified example where the outside temperature varies between 20°C and 12°C, while the control temperature remains at 16°C.

In Fig 1, the outside temperature is 20°C for half the time and 12°C for half the time, so the average temperature is 16°C. Since this is the same as the temperature inside the building it might seem to indicate that the building requires no heating. However, the diagram shows that the building will need heating for half the day, when the outside temperature is lower than the control temperature. Degree days allow for this: they are a measure of by how much and for how long the outside temperature is below a control temperature. In Fig 1, for each day the difference is 4°C for half a day, or two degree days.

Degree days normally applied to buildings can be of two kinds.

- ***heating degree days***, defined as the mean number of degrees by which the outside temperature on a given day is less than the base temperature, totalled for all the days in the period. These are of interest to operators of buildings such as offices, schools, hospitals, etc, in which the building temperature must be maintained above the outside temperature.
- ***cooling degree days***, defined as the mean number of degrees by which the outside temperature on a given day exceeds the base temperature, totalled for all the days in the period. These are of interest to operators of buildings such as air-conditioned buildings, and chill and cold stores, in which the building temperature must be maintained below the outside temperature.

3. How degree days are calculated

On any day the external temperature is not constant. It is, with only very rare exceptions, warmest during the day and coolest during the night. External temperature is, therefore, cyclic with a daily maximum and a daily minimum. For example, Fig 2 shows the variation of outside temperature in Liverpool on 16 - 17 February 1987.

For that part of the winter when the outside temperature is consistently below the control temperature, the number of heating degree days over a period is given by the difference between the average temperature and the control temperature, multiplied by the number of days in the period.

In the autumn and the early spring, however, it is common for the night temperature to drop below the base temperature whilst the daytime temperature remains above it. On such days, heating will not be required for part of the day. This is allowed for by using a formula based on the daily maximum and minimum temperatures, not just the average daily temperature used for calculating heating degree days above.

The usual method of calculating the degree days is based on a method originally proposed by the Meteorological Office. It is sometimes called the British Gas Method, because British Gas used it to calculate the heating degree days for the service that the Department of the Environment's Energy Efficiency Office now provides and publishes in 'Energy Management'.

The British Gas Method uses simple formulae which calculate the degree days per day from the daily maximum and minimum temperatures. These formulae are shown in Fig 3 for both heating and cooling degree days.

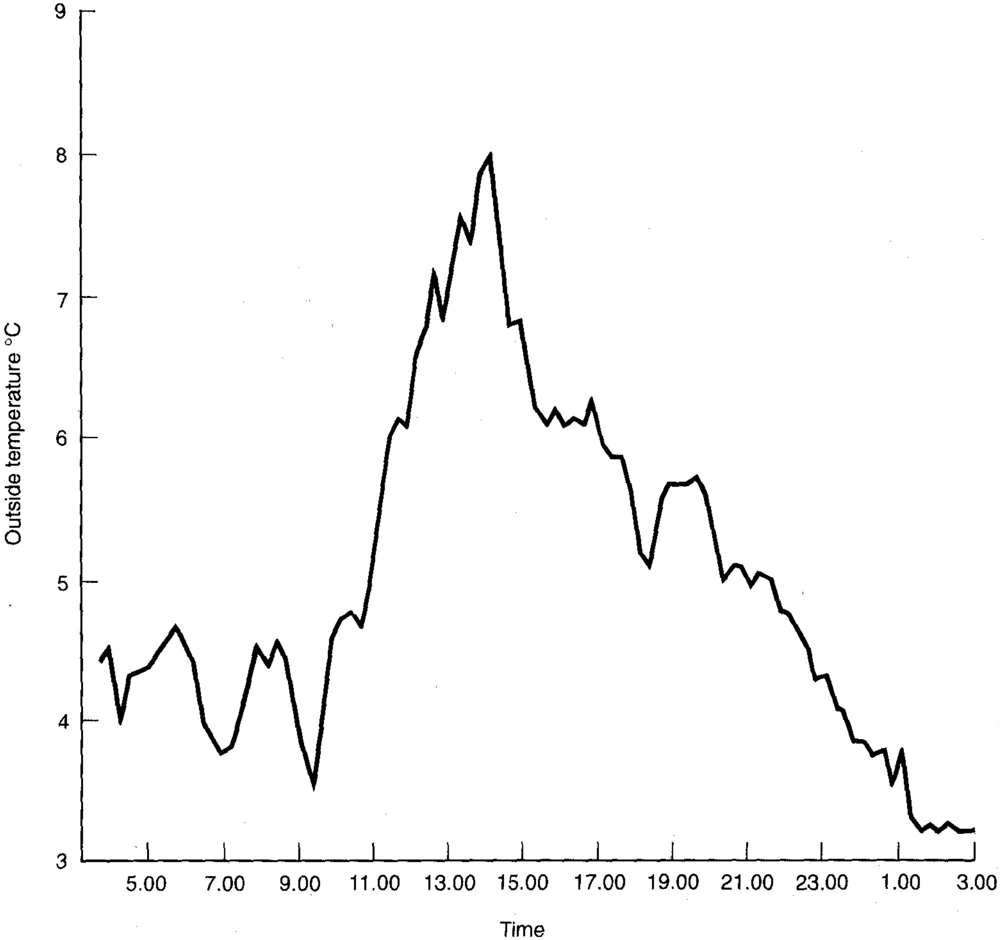


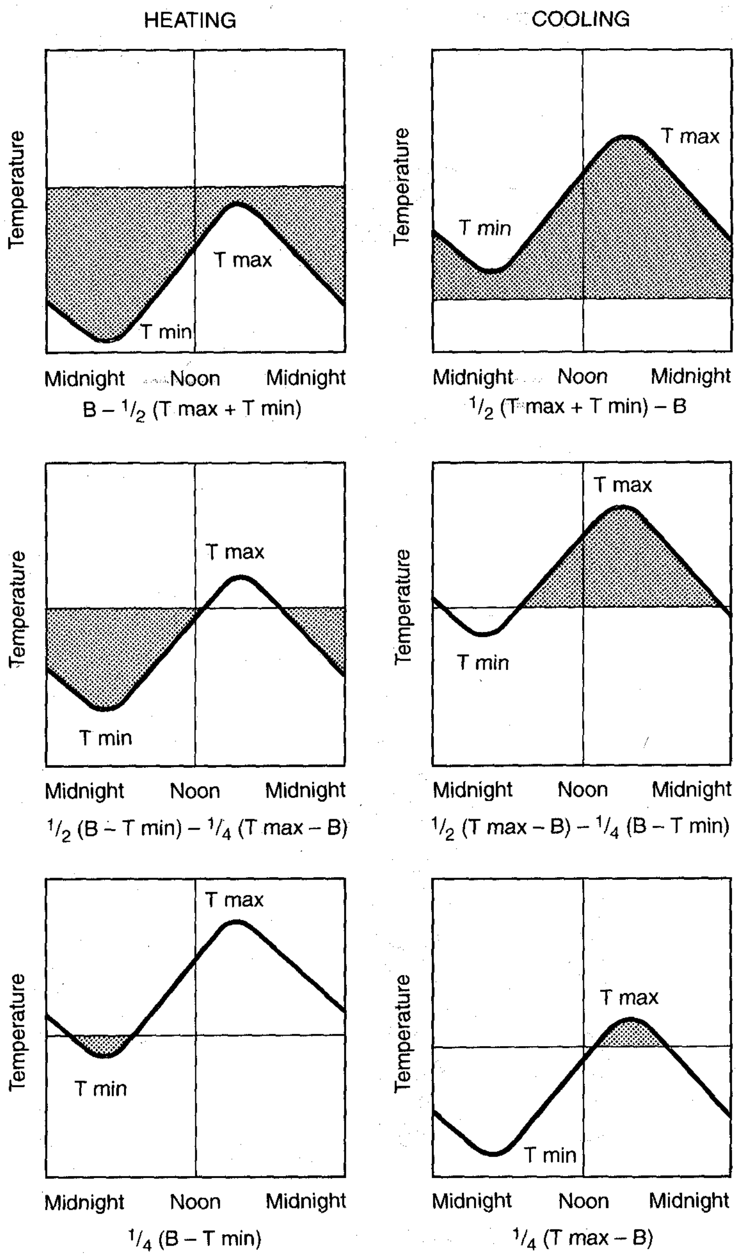
Fig 2 Outside temperature in Liverpool: 16 - 17 February 1987

The formulae in Fig 3 are highly simplified formulae and have built into them a number of assumptions, i.e.:

- a time difference of approximately 12 hours between the maximum and minimum temperatures;
- a symmetrical pattern of temperature variation (like a sine wave).

Since the result of the calculation is always the same for any given combination of base temperature and maximum and minimum temperatures, it is not necessary to work through the formulae every time.

Instead, the results can be calculated and presented as a table of degree days per day. Using the measured maximum and minimum temperatures for each day, the corresponding degree days can then be looked up in the table and totalled for any period - a week, a month or a year. Tables 1, 2 and 3 give these degree days per day to base temperatures of 18.5°C (heating), 15°C (heating) and 5°C (cooling) respectively.



Key: B = Base temperature (°C)
T max = Daily maximum temperature (°C)
T min = Daily minimum temperature (°C)

Fig 3 Degree day formulae for the British Gas Method

Table 1 Heating degree days calculated from maximum and minimum temperatures (Base 18.5°C)

Min. / Max.	10	9	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5
25	2.63	3.13	3.63	4.13	4.63	5.13	5.63	6.13								
24	2.88	3.38	3.88	4.38	4.88	5.38	5.88	6.38	6.88	7.38						
23	3.13	3.63	4.13	4.63	5.13	5.63	6.13	6.63	7.13	7.63	8.13					
22	3.38	3.88	4.38	4.88	5.38	5.88	6.38	6.88	7.38	7.88	8.38	8.88				
21	3.63	4.13	4.63	5.13	5.63	6.13	6.63	7.13	7.63	8.13	8.63	9.13	9.63			
20	3.88	4.38	4.88	5.38	5.88	6.38	6.88	7.38	7.88	8.38	8.88	9.38	9.88	10.38	10.88	11.38
19	4.13	4.63	5.13	5.63	6.13	6.63	7.13	7.63	8.13	8.63	9.13	9.63	10.13	10.63	11.13	11.63
18	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10.00	10.50	11.00	11.50	12.00
17	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10.00	10.50	11.00	11.50	12.00	12.50
16	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10.00	10.50	11.00	11.50	12.00	12.50	13.00
15	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10.00	10.50	11.00	11.50	12.00	12.50	13.00	13.50
14	6.50	7.00	8.50	9.00	9.50	10.00	10.50	11.00	11.50	12.00	12.50	13.00	13.50	14.00	14.50	15.00
13	7.00	7.50	8.00	8.50	9.00	9.50	10.00	10.50	11.00	11.50	12.00	12.50	13.00	13.50	14.00	14.50
12	7.50	8.00	8.50	9.00	9.50	10.00	10.50	11.00	11.50	12.00	12.50	13.00	13.50	14.00	14.50	15.00
11	8.00	8.50	9.00	9.50	10.00	10.50	11.00	11.50	12.00	12.50	13.00	13.50	14.00	14.50	15.00	15.50
10	8.50	9.00	9.50	10.00	10.50	11.00	11.50	12.00	12.50	13.00	13.50	14.00	14.50	15.00	15.50	16.00
9		9.50	10.00	10.50	11.00	11.50	12.00	12.50	13.00	13.50	14.00	14.50	15.00	15.50	16.00	16.50
8			10.50	11.00	11.50	12.00	12.50	13.00	13.50	14.00	14.50	15.00	15.50	16.00	16.50	17.00
7				11.50	12.00	12.50	13.00	13.50	14.00	14.50	15.00	15.50	16.00	16.50	17.00	17.50
6					12.50	13.00	13.50	14.00	14.50	15.00	15.50	16.00	16.50	17.00	17.50	18.00
5						13.50	14.00	14.50	15.00	15.50	16.00	16.50	17.00	17.50	18.00	18.50
4							14.50	15.00	15.50	16.00	16.50	17.00	17.50	18.00	18.50	19.00
3								15.50	16.00	16.50	17.00	17.50	18.00	18.50	19.00	19.50
2									16.50	17.00	17.50	18.00	18.50	19.00	19.50	20.00
1										17.50	18.00	18.50	19.00	19.50	20.00	20.50
0											18.50	19.00	19.50	20.00	20.50	21.00
-1												19.50	20.00	20.50	21.00	21.50
-2													20.50	21.00	21.50	22.00
-3														21.50	22.00	22.50
-4															22.50	23.00
-5																23.50

Table 2 Heating degree days calculated from maximum and minimum temperatures (Base 15.5°C)

Min. / Max.	10	9	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5
25	1.37	1.62	1.87	2.12	2.37	2.88	3.38	4.38								
24	1.37	1.62	1.87	2.12	2.63	3.13	3.63	4.13	4.63	5.13						
23	1.37	1.62	1.87	2.38	2.88	3.38	3.88	4.38	4.88	5.38	5.88					
22	1.37	1.62	2.13	2.63	3.13	3.63	4.13	4.63	5.13	5.63	6.13	6.63				
21	1.37	1.88	2.38	2.88	3.38	3.88	4.38	4.88	5.38	5.88	6.38	6.88	7.38			
20	1.63	2.13	2.63	3.13	3.63	4.13	4.63	5.13	5.63	6.13	6.63	7.13	7.63	8.13	8.63	9.13
19	1.88	2.38	2.88	3.38	3.88	4.38	4.88	5.38	5.88	6.38	6.88	7.38	7.88	8.38	8.88	9.38
18	2.13	2.63	3.13	3.63	4.13	4.63	5.13	5.63	6.13	6.63	7.13	7.63	8.13	8.63	9.13	9.63
17	2.38	2.88	3.38	3.88	4.38	4.88	5.38	5.88	6.38	6.88	7.38	7.88	8.38	8.88	9.38	9.88
16	2.63	3.13	3.63	4.13	4.63	5.13	5.63	6.13	6.63	7.13	7.63	8.13	8.63	9.13	9.63	10.13
15	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10.00	10.50
14	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10.00	10.50	11.00
13	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10.00	10.50	11.00	11.50
12	4.50	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10.00	10.50	11.00	11.50	12.00
11	5.00	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10.00	10.50	11.00	11.50	12.00	12.50
10	5.50	6.00	6.50	7.00	7.50	8.00	8.50	9.00	9.50	10.00	10.50	11.00	11.50	12.00	12.50	13.00
9		6.50	7.00	7.50	8.00	8.50	9.00	9.50	10.00	10.50	11.00	11.50	12.00	12.50	13.00	13.50
8			7.50	8.00	8.50	9.00	9.50	10.00	10.50	11.00	11.50	12.00	12.50	13.00	13.50	14.00
7				8.50	9.00	9.50	10.00	10.50	11.00	11.50	12.00	12.50	13.00	13.50	14.00	14.50
6					9.50	10.00	10.50	11.00	11.50	12.00	12.50	13.00	13.50	14.00	14.50	15.00
5						10.50	11.00	11.50	12.00	12.50	13.00	13.50	14.00	14.50	15.00	15.50
4							11.50	12.00	12.50	13.00	13.50	14.00	14.50	15.00	15.50	16.00
3								12.50	13.00	13.50	14.00	14.50	15.00	15.50	16.00	16.50
2									13.50	14.00	14.50	15.00	15.50	16.00	16.50	17.00
1										14.50	15.00	15.50	16.00	16.50	17.00	17.50
0											15.50	16.00	16.50	17.00	17.50	18.00
-1												16.50	17.00	17.50	18.00	18.50
-2													17.50	18.00	18.50	19.00
-3														18.50	19.00	19.50
-4															19.50	20.00
-5																20.50

Table 3 Heating degree days calculated from maximum and minimum temperatures (Base 5°C)

Min.	10	9	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5
Max.																
25	12.5	12.0	11.5	11.0	10.5	10.0	9.75	9.5	9.25							
24	12.0	11.5	11.0	10.5	10.0	9.5	9.25	9.0	8.75	8.5						
23	11.5	11.0	10.5	10.0	9.5	9.0	8.75	8.5	8.25	8.0	7.75					
22	11.0	10.5	10.0	9.5	9.0	8.5	8.25	8.0	7.75	7.5	7.25	7.0				
21	10.5	10.0	9.5	9.0	8.5	8.0	7.75	7.5	7.25	7.0	6.75	6.5	6.25			
20	10.0	9.5	9.0	8.5	8.0	7.5	7.25	7.0	6.75	6.5	6.25	6.0	5.75	5.5		
19	9.5	9.0	8.5	8.0	7.5	7.0	6.75	6.5	6.25	6.0	5.75	5.5	5.25	5.0	4.75	
18	9.0	8.5	8.0	7.5	7.0	6.5	6.25	6.0	5.75	5.5	5.25	5.0	4.75	4.5	4.25	4.0
17	8.5	8.0	7.5	7.0	6.5	6.0	5.75	5.5	5.25	5.0	4.75	4.5	4.25	4.0	3.75	3.5
16	8.0	7.5	7.0	6.5	6.0	5.5	5.25	5.0	4.75	4.5	4.25	4.0	3.75	3.5	3.25	3.0
15	7.5	7.0	6.5	6.0	5.5	5.0	4.75	4.5	4.25	4.0	3.75	3.5	3.25	3.0	2.75	2.5
14	7.0	6.5	6.0	5.5	5.0	4.5	4.25	4.0	3.75	3.5	3.25	3.0	2.75	2.5	2.25	2.0
13	6.5	6.0	5.5	5.0	4.5	4.0	3.75	3.5	3.25	3.0	2.75	2.5	2.25	2.0	1.75	1.5
12	6.0	5.5	5.0	4.5	4.0	3.5	3.25	3.0	2.75	2.5	2.25	2.0	1.75	1.5	1.25	1.0
11	5.5	5.0	4.5	4.0	3.5	3.0	2.75	2.5	2.25	2.0	1.75	1.5	1.25	1.0	0.75	0.5
10	5.0	4.5	4.0	3.5	3.0	2.5	2.25	2.0	1.75	1.5	1.25	1.0	0.75	0.5	0.25	0
9		4.0	3.5	3.0	2.5	2.0	1.75	1.5	1.25	1.0	0.75	0.5	0.25	0		
8			3.0	2.5	2.0	1.5	1.25	1.0	0.75	0.5	0.25	0				
7				2.0	1.5	1.0	0.75	0.5	0.25	0						
6					1.0	0.5	0.25	0								
5						0										

(Extrapolation to temperatures below -5°C min is obvious)

The great advantage of basing calculations of degree days on maximum and minimum temperatures is that these are easily measured. Maximum/minimum thermometers are cheap and easy to obtain, and are a standard instrument in a weather station. Daily maximum and minimum temperatures are also collected regularly by the Meteorological Office at a large number of weather stations.

To get more accurate results would require more continuous recording of temperature, from which the degree days can be calculated directly. The microcomputer Building Energy Management Systems (BEMS) which are often used to control the heating of buildings are able to do this, and usually provide measured degree days which are more accurate than degree days based on the formulae. Indeed, it is more difficult to program such an electronic system to identify the maximum and minimum temperatures and to compute degree days using the British Gas formulae, than it is to get the system to calculate them directly over intervals of 15 minutes.

4. Base temperatures

Normally a heated building would be regulated to 18.3°C (65°F) in the coolest temperature controlled part of the building. This is above the minimum temperature required by the Factories Act 1961 of 15.5°C, and the Shop, Offices and Railway Premises Act 1963 of 16°C, and is below the maximum temperature set by the 1980 Fuel and Electricity (Heating) (Control) (Amendment) Order of 19°C.

The heating degree day tables usually published, however, are for a base temperature of 15.5°C. This base is intended to reflect the fact that not all the heat in a building comes from the heating plant - people, lights and machines such as computers, photocopiers, typewriters and the like, also contribute to the heat input into the building. Allowing for these contributions in the base temperature is called *occupancy correction*.

There is a second correction made to the base temperature which allows for the fact that many buildings are not heated at all until the outside temperature falls to a level somewhat below the control temperature. This is sometimes called the *dead-zone for control*.

A third type of correction is an *activity correction* which takes account of the fact that the temperature which is comfortable depends on the activity of people in the building. People on the move feel more comfortable at a lower temperature than, for example, patients in a hospital.

There is a simple mathematical argument which shows that the best way to allow for these corrections is simply to reduce the base temperature. The basis of this argument is that there is a temperature rise in the building attributable to all these factors, and this should be subtracted from the building control temperature to obtain the new base temperature.

There are various suggested values for adjusting base temperatures for different types of building, ranging in some cases from 2°C to 9°C. The corrections most often recommended are those given in the CIBSE Guide, produced by the Chartered Institution of Buildings Services Engineers (Part B18), as shown in Table 4.

In practice most users accept a base temperature of 15.5°C because this is the temperature adopted by the CIBSE Guide for typical buildings. 15.5°C is the base used for most of the commonly published tables and is the most generally suitable, at least for the purpose of sizing heating plant and for users beginning to monitor energy use in buildings. The National Health Service is the only major exception, always using a base temperature of 18.5°C.

A table of degree days to base 15.5°C is published every other month in the Energy Efficiency Office's journal 'Energy Management'. An example of this is shown in Table 5. For each of 17 regions it gives the degree days for each month in the current heating season, the degree days for the immediately preceding heating season and the 20 year average.

5. Cooling degree days

Cooling degree days are used much less than heating degree days. One of their important applications is for operators of air-conditioned buildings such as offices and large stores. As with heated buildings, it is necessary to adjust the base temperature to allow for the fact that heat gains due to occupancy and machines need to be extracted from the building. However, as yet there seems to be no general agreement on what these adjustment levels should be and many users work with a 15.5°C base temperature.

Table 4 Commonly used correction intervals for degree day base temperatures

Class of building	Building structure	(°C)
1	Building with large area of external glazing, much internal heat-producing equipment* and densely populated	5 to 6
2	Buildings with one or two of the above factors	4 to 5
3	'Traditional' buildings with normal glazing, equipment and occupancy	3 to 4
4	Sparsley occupied buildings with little or no heat-producing equipment and small glazed area	2 to 3
5	Dwellings	5 to 8

Notes:

* Unless separately allowed for in the design heat loss.
Add 1°C for single storey buildings.

Source CIBSE Guide

Table 5 Example heating degree day table to base 15.5°C as published in 'Energy Management'

	Thames Valley	South Eastern	Southern	South Western	Severn Valley	Midland	West Pennines	North Western	Borders	North Eastern	East Pennines	East Anglia	West Scotland	East Scotland	North East Scotland	Wales	Northern Ireland
SEPT	57	87	80	58	71	94	81	95	107	89	79	76	107	109	126	77	102
	57	74	67	48	44	79	79	95	99	85	77	75	114	112	140	75	106
	41	62	66	43	36	64	51	78	90	68	65	62	112	110	128	60	74
OCT	129	160	144	112	144	171	152	166	181	168	156	153	178	186	197	137	168
	111	138	135	106	96	149	141	153	161	151	154	123	185	190	209	141	177
	116	142	150	113	123	162	146	155	146	160	146	151	182	167	191	150	155
NOV	252	278	256	212	255	286	279	296	298	292	280	281	307	312	323	239	289
	188	203	218	195	199	239	229	236	235	239	238	213	262	257	260	223	281
	325	344	341	273	287	352	344	374	349	371	354	364	386	376	391	302	343
DEC	333	356	327	274	329	360	348	360	362	364	353	362	359	370	381	304	345
	302	321	316	250	270	340	315	311	326	347	341	324	325	332	321	289	320
	245	265	262	205	237	298	290	301	324	323	302	275	320	343	366	270	312
JAN	352	375	347	298	351	379	365	372	380	380	370	386	375	386	399	332	365
	446	468	467	385	409	467	447	450	406	457	448	488	468	439	439	407	456
	354	368	356	282	324	386	376	392	387	399	391	387	411	405	411	335	384
FEB	309	331	314	278	317	343	330	339	349	344	333	344	344	352	365	310	332
	345	376	352	280	335	406	353	356	349	375	376	396	364	349	347	326	326
	447	467	448	407	432	482	437	434	414	457	463	478	436	422	448	439	402
MAR	285	310	297	270	294	320	308	320	332	318	306	319	320	328	344	298	316
	315	346	339	287	295	344	335	342	348	345	340	345	352	355	358	329	339
	298	335	322	290	292	335	322	322	341	339	328	328	327	326	352	321	325
APR	202	230	219	203	215	238	228	243	265	240	223	237	242	260	276	235	243
	180	202	209	188	180	227	218	229	251	223	222	214	234	247	266	221	222
	255	277	288	268	265	296	286	300	320	305	296	280	304	313	321	311	307
MAY	115	148	146	135	133	156	142	164	195	159	143	146	167	193	206	162	170
	115	135	134	116	117	166	139	157	201	172	160	159	163	188	203	169	176
	116	141	152	142	121	142	130	156	171	138	136	123	164	170	171	166	166
JUN	50	75	70	61	59	79	69	84	108	78	69	73	85	102	112	85	87
	68	81	84	67	71	105	97	116	138	114	107	99	122	133	143	122	109
	48	64	71	60	46	77	66	88	116	78	77	75	101	111	115	83	84
JUL	25	45	42	33	31	48	43	57	75	50	43	46	64	72	86	51	62
	20	29	42	23	18	37	29	52	66	42	38	33	62	65	65	56	53
	20	30	39	29	18	40	42	56	58	46	43	34	71	64	71	56	56
AUG	28	50	44	32	36	53	44	60	75	52	43	45	67	74	88	46	65
	31	49	42	33	29	52	48	62	73	55	56	49	88	83	87	72	77
	40	59	64	61	47	76	75	92	105	85	81	59	99	114	119	88	107
	2137	2445	2286	1966	2235	2527	2389	2556	2727	2534	2398	2468	2615	2744	2903	2276	2544
TOTALS	2178	2422	2405	1978	2063	2611	2430	2559	2653	2605	2557	2518	2739	2750	2838	2430	2642
	2305	2554	2559	2173	2228	2710	2565	2748	2821	2769	2682	2616	2913	2921	3084	2581	2715

Degree day users requiring early figures may obtain these direct from the Regional Energy Efficiency Officers whose telephone numbers are listed in 'Energy Management'.
The first row of figures in each month are averaged for over 20 years to 1979, second and third are respectively actual values for period September 1984 to August 1985 and September 1985 onwards. Figures for the most recent months are subject to possible revision when fully quality-controlled data becomes available to the Meteorological Office. This normally takes about eight weeks.
Figures in this table are now finally adjusted to June 1986.
Data supplied by the Meteorological Office (Met. 03)

The other main area of cooling degree day use is in refrigerated storage, of which there are three kinds:

- chill store operators for storing fresh foods (milk, fresh vegetables, cut flowers, etc) at 5°C;
- frozen food storage at -18°C;
- deep frozen food storage at -30°C.

These are, however, specialised applications which require special consideration, because the efficiency of refrigeration plant is also related to degree days. These applications will not be considered further in this Booklet. Further information on the operation of refrigeration plant can be found in Fuel Efficiency Booklet No 9 - 'The Economic Use of Refrigeration Plant'.

6. Uses of degree days

There are three main uses of degree days:

- assessing the heating needs of buildings for the purpose of designing heating systems;
- assessing the heat losses of buildings for the evaluation of insulation and other energy saving measures;
- monitoring building energy use.

The first two uses are very different in character from the third. In the first two applications, degree days are used in conjunction with the 'U'-values of the materials of construction of the building to establish the rate of heat loss through a part of, or the entire, building fabric. What is important in these applications is the absolute number of degree days in the evaluation period.

The third application requires a comparison of the pattern of energy use in the building with the pattern of variation in outside temperature, as an indicator of the level of control achieved or to evaluate the effectiveness of energy saving measures. Here it is the scale of variation, not the absolute measure of degree days, which is most important.

6.1 Heat loss from part of a building

The 'U'-value of a material or structure is the rate at which heat will pass through a given area for a given temperature difference. It is a property of the material or the component materials in a structure and is usually measured in watts per square metre per degree Celsius ($W/m^2/°C$).

The 'U'-value of an 11" wall comprising a brick outer leaf, cavity and low density block inner leaf is 1.1 $W/m^2/°C$. Divide this by 1,000 and it becomes 0.0011 $kW/m^2/°C$. To obtain the yearly heat loss it is necessary to know the extent and duration of the temperature difference across the wall - this measure is given by the degree days.

Example

If the building with a 'U'-value of 0.0011 $kW/m^2/°C$ were located in the north-west of England, the 20 year running average of annual degree days would be 2,549. Multiply this by 24 to get degree hours per year, and multiply by the kilowatt 'U'-value to convert to $kWh/year/m^2$.
Therefore:

$$\text{Heat loss} = \frac{1.1 \times 2{,}549 \times 24}{1000} = 67\ kWh/year/m^2$$

In this way it is possible to measure the heat loss from any part of a building, provided the area of the structure, the 'U'-value of the material and the degree days for the location are known.

The 'U'-values of some commonly used constructional materials are given in Table 6. 'U'-values for other structures are often listed in books on energy management and building design. The CIBSE Guide (Part A3) lists 'U'-values for most common structures and many materials. Eurisol UK, an organisation representing UK manufacturers of mineral wool products, produces a useful booklet on 'U'-values of structures incorporating mineral wool products. Manufacturers of other insulation products are normally willing to provide 'U'-values on request.

6.2 Total heat loss for a building

Given the area and the 'U'-value of each surface of a building, it is simple to determine the heat loss through the fabric of an entire building by performing the calculation given in Section 6.1 for each surface of a building.

The second area of heat loss from a building is through ventilation. If the building has a volume, V, and the heated air in the building is exchanged for cold air from outside N times per hour, then the hourly ventilation heat loss is given by:

$$N \times V \times S\ (T_{inside} - T_{outside})$$

where S is the specific heat of air which is 1.30 $kJ/m^3/°C$, or 0.36 $Wh/m^3/°C$. On an annual basis ($T_{inside} - T_{outside}$) would be replaced by the annual degree days, N would be multiplied by 24 to give air changes per day, and S in watt hours (Wh) would be divided by 1,000 to give kWh.

Table 6 Some likely 'U'-values of typical insulated and uninsulated buildings	
	W/m^2/°C
Roofs	
Pitched, covered with slates or tiles, roofing felt underlay, plasterboard ceiling	1.70 - 2.00
Pitched, covered with slates or tiles, with 100mm fibre roll insulation above ceiling	0.35
Pitched, covered with slates or tiles, with 75mm rigid insulating board replacing plasterboard	0.39 - 0.42
Steel or asbestos cement roofing sheets, no lining	6.1 - 6.7
Steel or asbestos cement, rigid insulating lining board 75mm	0.40
Flat roof, three layers felt on chipboard or timber sheeting plasterboard ceiling	1.54
Flat roof, three layers felt on 70mm rigid insulating board under felt roofing	0.37 - 0.40
Flat roof, three layers felt, 60mm glass fibre roll insulation laid above ceiling	0.50
Flat roof, three layers felt etc, on metal decking, no ceiling	3.3
Flat roof, three layers felt etc, rigid insulating board between felt and deck 70mm	0.50
Walls	
Steel or asbestos cement cladding sheets	5.3 - 5.7
Steel or asbestos cement cladding sheets with plasterboard lining and 100mm layer of fibre roll insulation	0.40
Steel or asbestos cement cladding sheets with 50mm rigid insulating board decoratively faced	0.60
Brick/cavity/brick 11" wall, internally plastered	1.4 - 1.9
Brick/cavity/brick 11" wall, cavity filled with loose, foamed or slab insulation	0.55 - 0.60
Brick/cavity/low density block 11" normal wall, internally plastered	0.9 - 1.5
Brick/cavity/low density block 11" normal wall, cavity filled with loose, foamed or slab insulation	0.45 - 0.60
Brick/cavity/low density block 11" normal wall, normal cavity internal surface battened, 50mm fibre roll insulation, plasterboard cover	0.45 - 0.55
Glazing	
Single glazing	5.7
Double glazing (sealed units)	4.3
Treble glazing (sealed double unit and separate inner sheet)	3.2

Annual ventilation heat loss then becomes:

$$N \times 24 \times \frac{0.36}{1{,}000} \times \text{degree days}$$

Adding together the calculated fabric and ventilation heat losses gives the total heat loss of the building. Various adjustments can be made to take account of the sun beaming through windows, wind factors and so on, but the introduction of degree days forms the essential basis of the assessment.

Published degree days to base 15.5°C (or to base 18.5°C for a hospital or similar establishment) would normally be used for this kind of assessment, with the annual degree days being multiplied by a suitable factor to allow for such facts as a building not being occupied at weekends, etc.

6.3 Assessment of specific measures

The second use of degree days is to assess heat losses in an individual component of a building, in order to evaluate the benefits of specific energy saving measures.

One common measure applied is insulation. To assess this application it is important to calculate the heat loss under the conditions which actually prevail in the building so far as possible.

In the case of roof insulation, account needs to be taken of the fact that the temperature under the ceiling is usually greater than the temperature of the main volume of the building, because hot air tends to rise. If measurements show that the temperature is not significantly different, it can be ignored; however, the difference is often far greater than expected. Temperatures of 25°C at ceiling level are common and 35°C is not unknown. These temperatures can have a very significant effect on the viability of an insulation project.

A full assessment therefore involves determining the degree days for the building concerned *to a base temperature the same as that on the inside of the surface*. The calculation of degree days to other base temperatures is covered in Section 7.

6.4 Degree days for monitoring (CUSUM)

The applications discussed so far for degree days are those which would be used regularly by building or heating plant designers, contractors or consultants. The energy manager of a building may occasionally need to carry out a building heat loss assessment, but would not normally be doing this routinely. The recent enormous increase in interest in degree days among energy managers has been due to their use in monitoring energy use in buildings. Indeed, more people probably now use degree days for monitoring than for any other purpose.

Example benefit calculation

A flat roof over a factory comprising three lays of felt on chipboard or timber, with a plasterboard ceiling has a 'U'-value of 1.54 W/m^2/°C. Replacing the ceiling with a 70 mm rigid insulating board would reduce the 'U'-value to 0.4 W/m^2/°C.

To calculate the difference in annual heat loss it is necessary to:

- divide the difference in 'U'-value by 1,000 to obtain kWh;
- multiply the kWh by the annual degree days x 24 (degree hours).

Thus, for a building in north-east Scotland, where the 20 year average of annual degree days to base 15.5°C is 2,810, the difference in annual heat loss is:

$$(1.54 - 0.4) \times \frac{2{,}810}{1{,}000} \times 24 = 76.9 \text{ kWh/m}^2$$

It is then necessary to calculate the cost of this heat. Usually only electricity and gas (since April 1992) are sold in kWh. Appendix 1 gives factors which can be used to convert the price of each of the common fuels from their usual units into pence per kWh. In this example, suppose the boiler was fuelled by gas oil costing 13 pence per litre. The conversion factor to pence per kWh is 0.0936. Taking the boiler efficiency as 70% (this would be measured or estimated), the energy savings through reduction of 'U'-value would be:

$$76.9 \times 13 \times 0.0936 \times \frac{100}{70} = 134 \text{ pence/m}^2\text{/year}$$

If the acceptable payback on insulation measures were three years, any measure which could be installed for less than £4 per square metre would be viable.

There are sound theoretical reasons why a graph of energy use in a building against degree days should be close to straight line. Fig 4 shows the form of graph obtained, with the best-fit line drawn in, for which there are three principal features:

- ***The intercept***, i.e. the point where the line cuts the energy axis at zero degree days, which is the energy that is apparently needed by the building when heat losses would be at a minimum. The energy use at this point is often called the *weather unrelated demand* or *degree-day unrelated demand.*
- ***The slope*** or gradient, which is a measure of the amount by which the energy consumption rises for each additional degree day. This is often called the *weather related demand* or *degree-day related demand.*
- ***The scatter*** or actual positioning of the data points in the graph, which is an indication of the extent to which the energy use in the buildings is controlled, i.e. determined by the weather (degree days) rather than by other factors such as poor physical control, unrestrained waste, etc.

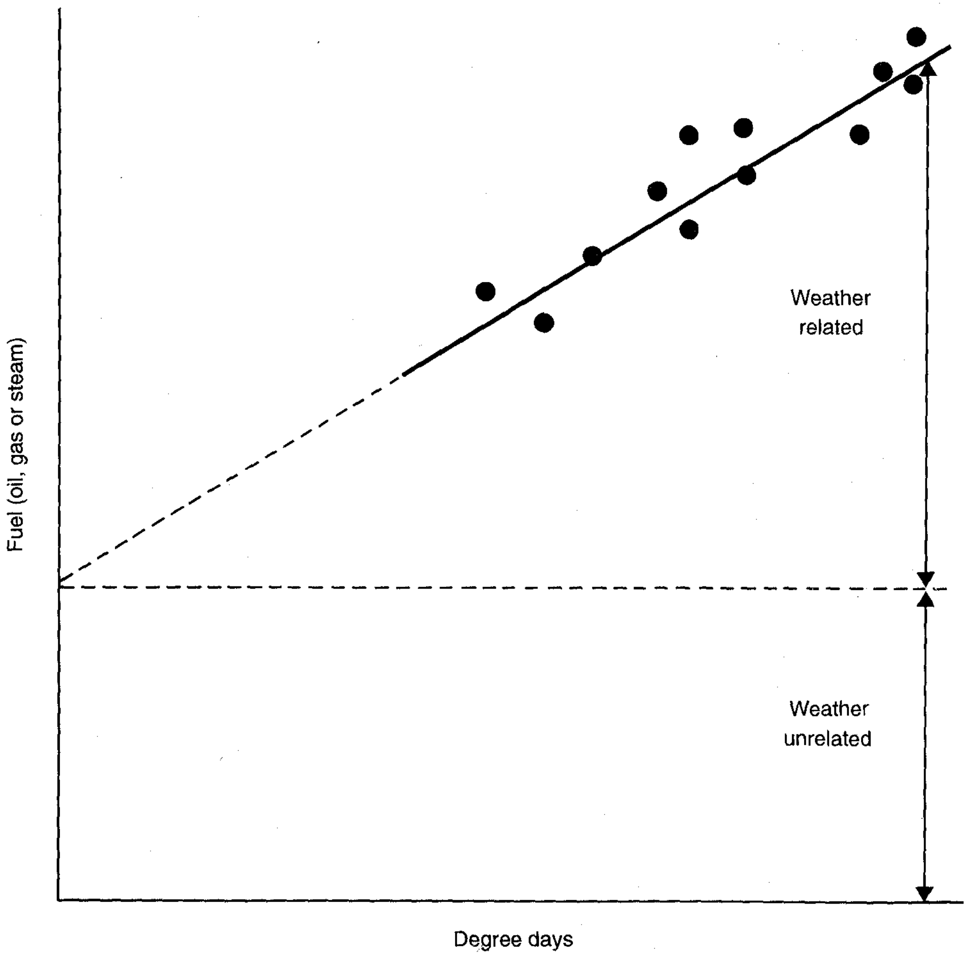


Fig 4 Relating energy use to degree days

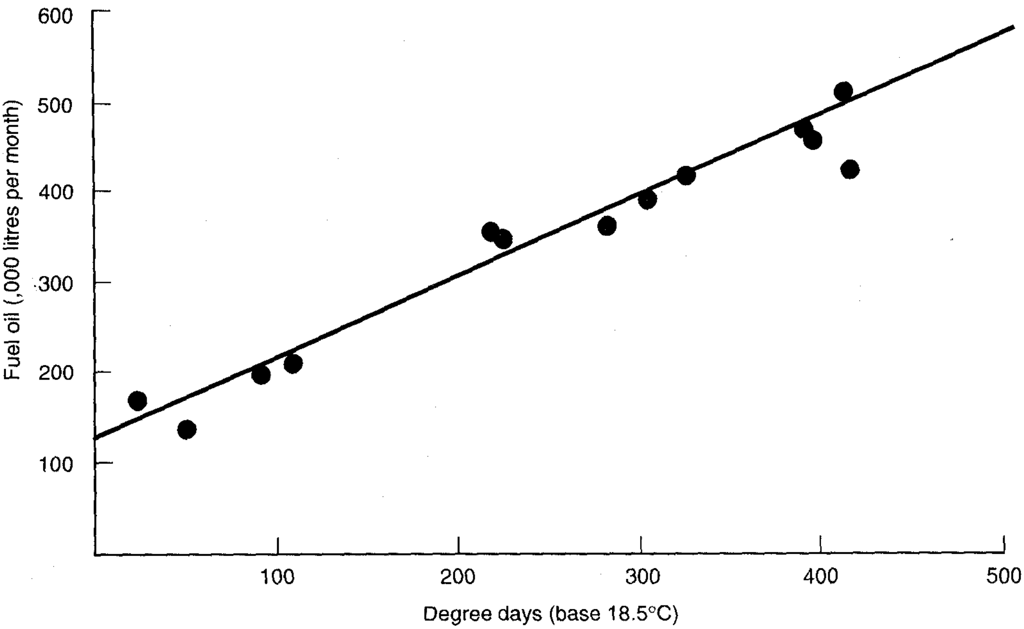


Fig 5 Fuel use compared with degree days for North Middlesex Hospital: April 1983 - April 1984

Fig 5 shows an example of a moderately well-controlled building, North Middlesex Hospital, where the degree days used were to base 18.5°C. This shows that the weather unrelated demand of the hospital was 130,000 litres of oil per month, and the weather related use was 920 litres per degree day, i.e. for every degree the outside temperature fell below the base temperature, fuel use increased by 920 litres a month.

The main value of this kind of graph is in its use for monitoring the benefits of energy saving measures. The most sensitive technique for evaluating savings is a method known as the *CUmulative SUM deviation method*, usually abbreviated to *CUSUM*.

The method comprises six steps, explained here with the North Middlesex Hospital used as an example.

Step 1 Plot a graph, such as that shown in Fig 4, to establish a base pattern of consumption against which to assess subsequent demand. Fig 5 shows a suitable base line for the chosen period of April 1983 to April 1984.

Step 2 Convert the base line to a formula derived from the graph (see Appendix 2).

Step 3 Use the formula to calculate the predicted energy usage, using the degree days in each month (including the period covered by the base line and subsequent months) as shown in Table 7, column 3.

Step 4 Subtract the predicted consumption from the actual consumption in each month, as shown in Table 7, column 4.

Step 5 Obtain the cumulative total, as shown in Table 7, column 5, which is CUSUM.

Step 6 Plot CUSUM against time in months, weeks, etc. This is shown in Fig 6.

Table 7 Calculation of CUSUM for the North Middlesex Hospital						
		Oil Consumption thousand litres Actual	Degree Days	Predicted Consumption thousand litres	Difference thousand litres	CUSUM thousand litres
		1	2	3	4	5
1983	April	417	321	425	-8	-8
	May	353	217	329	23	16
	June	200	90	213	-13	3
	July	173	22	150	23	26
	August	133	46	176	-38	-12
	September	212	107	228	-16	-28
	October	343	225	337	7	-21
	November	387	304	410	-22	-43
	December	468	389	488	-19	-62
1984	January	506	427	523	-17	-79
	February	421	415	512	-91	-170
	March	452	396	494	-42	-212
	April	360	282	390	-30	-241
	May	285	238	368	-64	-305
	June	169	95	217	-48	-353
	July	155	59	184	-29	-381
	August	122	41	168	-45	-427
	September	126	123	243	-117	-543
	October	241	199	313	-72	-615
	November	263	276	384	-120	-735
	December	330	395	493	-163	-898
1985	January	410	539	626	-216	-1,113
	February	396	429	524	-129	-1,124
	March	380	408	505	-125	-1,367
	April	309	264	360	-63	-1,430
	May	241	197	309	-69	-1,500
	June	169	137	264	-86	-1,586
	July	147	59	205	-37	-1,623
	August	155	90	228	-58	-1,681
	September	154	94	232	-62	-1,743
	October	195	195	308	-114	-1,857

The CUSUM graph has a characteristic shape. The first part of the graph covers the period which corresponds to the base line. Clearly CUSUM, which represents the difference between the base line and the data points over the base line period, should follow a trend which represents the random fluctuations of energy consumption and should oscillate about zero. (If the line has been drawn by eye and not by statistical calculation, it may show a slight slope or bias but this should only be small.)

This trend will continue until something happens to alter the pattern of consumption. Any change would be expected to be to a new pattern, representing a consistent deviation from the original pattern. On the CUSUM graph this commonly produces a straight line so that the graph is found to be comprised of a series of straight sections joined by breaks. Each break represents the onset of the effect of an energy saving measure.

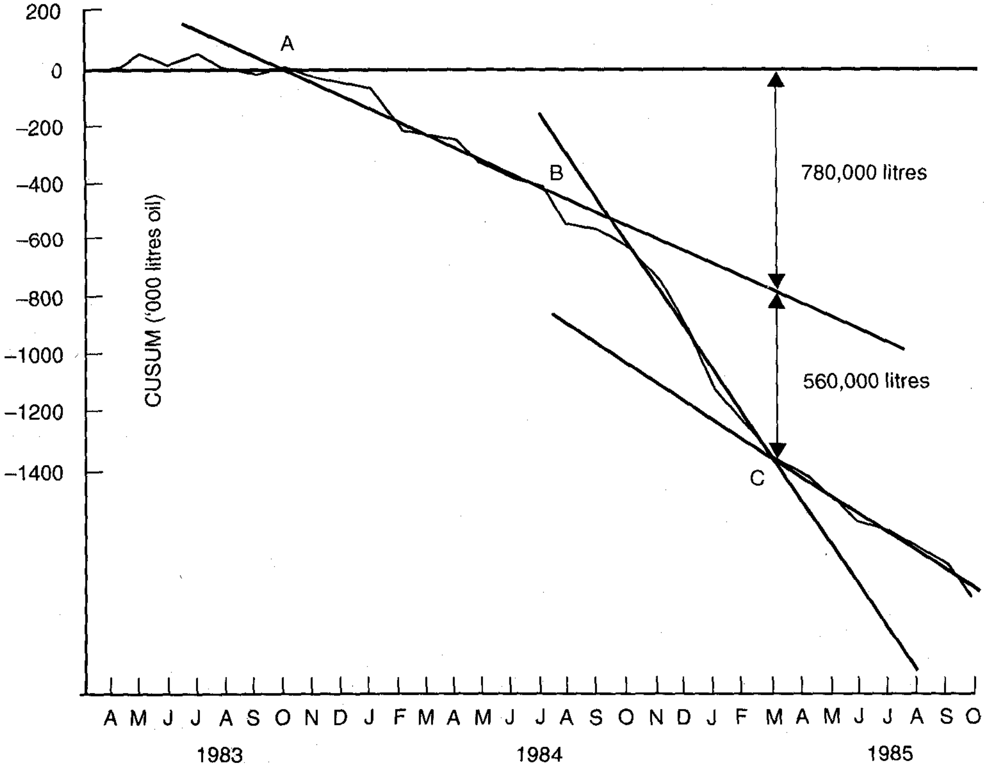


Fig 6 CUSUM for North Middlesex Hospital (Base 18.5°C)

Clearly, if nothing happens to change the pattern of consumption, the straight sections of the CUSUM graph will simply continue unaltered. Extrapolating the trend, therefore, enables the contribution to total savings of each individual measure up to a given date to be identified, as shown in Fig 6.

The CUSUM method is not used solely for monitoring energy use in buildings. It is also used for monitoring energy use in processes and is an increasingly widely used technique in production management.

There are two particular features of the CUSUM graph when it is used for monitoring energy use in buildings which need to be noted:

- When energy saving measures directly affect the building space heating requirements, there will be no savings produced in the period when the space heating is not used. Over several heating seasons the graph therefore takes on a stepped appearance.
- Degree days do not vary randomly throughout the year but show a consistent trend towards higher degree days as the year progresses from autumn to winter, and towards lower degree days as the year progresses from winter to spring. This causes what would otherwise be straight sections of the graph occasionally to become slightly curved or to appears as arcs.

Both of these features are evident in Fig 6. The first break in the line, A, was due to a programme of good housekeeping measures, which provided savings both during the heating season and in summer. The second break, B, in August 1984 was due to the installation of an electronic Building Energy Management System (BEMS). Around March or April 1985, C, the reduced heating needs caused the savings to diminish as the year progressed into summer, and the graph then began to follow the trajectory of the line of the previous summer. (The good housekeeping measures ensured a downward trend in the summer. Without these the graph would have been horizontal in summer, which is often the case.)

Before leaving the subject of monitoring, it should be mentioned that there are other methods apart from CUSUM that can be used to relate energy use to degree days, which are considered to be simpler. One method is to divide the energy use by the degree days, to obtain the energy use per degree day. It is important to recognise that, where there is any degree-day unrelated use, a meaningful comparison can only be obtained for months in which the degree days are equal. As this only happens occasionally, and often not in the same heating season, it usually proves to be too long an interval to have to wait to discover that a measure is not working or is producing less savings than expected. The advantage of the CUSUM method is that it can follow energy trends on a lot shorter timescale and offers much greater precision in the quantification of savings.

7. Changing the base temperature

Although it is widely accepted that, where possible, an appropriate base temperature for degree days should be selected with regard to the application concerned, and that the best way to deal with occupancy and other corrections is to alter the base temperature, published degree days are only readily available for two base temperatures (15.5°C and 18.5°C).

The only absolutely reliable way to obtain degree days at another base temperature is to work from the daily maximum and minimum temperatures, but information in this form is cumbersome to handle and may be difficult to obtain accurately.

Various approximation methods have been devised to allow degree days to be obtained for other base temperatures, though not all of them are equally reliable.

One method of changing base temperature which *used* to be recommended was to use the measured degree days for a known base temperature, and to extrapolate these between the extreme maximum and minimum temperatures, and the extreme maximum plus 5°C. It is now recognised that this gave unacceptably crude results and could lead to substantial errors in some instances. In any case, the extreme maximum and minimum temperature in the month may not be readily available.

A more reliable method of obtaining degree days to any base is to use empirical formulae based on the monthly mean air temperature (which is itself calculated from daily maximum and minimum temperatures). There are two such formulae: one is known as Thom's Formula; the second is Hitchin's Formula, which gives almost identical results but is easier to use.

Hitchin's Formula is:

$$\text{Average degree days per day} = \frac{(t_b - t_o)}{1 - e^{-k\,(t_b - t_o)}}$$

Where:

t_b is the base temperature
t_o is the mean air temperature in the month
k is a constant

Multiplying the average degree days per day by the number of days in the month gives the degree days for the month. The value of k varies slightly according to location, and has been determined from 20 years of weather data for five sites in Britain. These values are given in Table 8.

Table 8 Best fit values of k in Hitchin's Formula (1952 -1971)	
Site	k
Heathrow	0.66
Manchester	0.70
Birmingham	0.66
Glasgow	0.74
Cardiff	0.78
Mean	0.71

It is found that using the appropriate value of k in any of these locations gives total degree days per month which are never more than 5.5 degree days in error. The average k value of 0.71 is recommended for any other location in the UK for which a local value of k is not available. When this value is applied to the same sites in the locations given, the degree days are only in error by more than 5.5 degree days for one month in 14 (7% frequency error), so the average value can be recommended for general use.

Since Hitchin's Formula depends only on the value of k and the mean air temperature, it is possible to provide a table from which to estimate the degree days per day for any value of $(t_b - t_o)$, i.e. the difference between the required base temperature and the mean monthly temperature. These values are given in Table 9 for k = 0.71.

Table 9 Estimation of monthly degree days to any base temperature (inland Britain) using Hitchin's Formula with k = 0.71	
Base temperature minus mean monthly temperature	Degree days per day
°C	
10	10.01
9	9.02
8	8.03
7	7.05
6	6.09
5	5.15
4	4.25
3	3.40
2	2.64
1	1.97
0	1.43
-1	0.97
-2	0.64
-3	0.40
-4	0.25
-5	0.15
-6	0.09
-7	0.05
-8	0.03
-9	0.02
-10	0.01

Calculation of degree days per day is then very straight forward:

- For all months in which the mean outside air temperature is different from the base temperature by 10°C or less, the degree days per day can be read directly from Table 9.
- For months in which the temperature difference is more than 10°C, the number of degree days per day is simply the difference between the outside air temperature and the base temperature.

Example

Calculate the degree days for a base temperature of 8°C for January 1985 at Plymouth.

From Appendix 3, the mean air temperature in Plymouth during January is 3.2°C. The difference between the base temperature and mean air temperature is therefore

8.0 - 3.2 = 4.8°C.

From Table 9 the degree days per day are 5.15 at a difference of 5 and 4.25 at a difference of 4. Interpolating between values, the value of degree days per day at 4.8 would be 4.97. The number of days in January is 31, so the degree days in the month are 4.97 x 31 = 154.1.

Alternatively, using Hitchin's Formula:

$$\text{Degree days per day} = \frac{8.0 - 3.2}{1 - e^{-0.71\,(8.0 - 3.2)}}$$

$$= \frac{4.80}{1 - 0.0331}$$

$$= 4.964$$

Degree days for month = 31 x 4.964 = 153.9

The same procedure can be used to obtain the total degree days for the evaluation of degree days for a year.

Example

Suppose it was necessary to estimate the roof heat loss for a high ceiling building in Manchester, where the temperature under the roof was 25°C and the ceiling 'U'-value was 1.54 W/m^2/°C. The base temperature would be the temperature immediately next to the roof fabric, i.e. t_b = 25°C. The monthly mean air temperature, t_o, is given in Appendix 3 enabling the following calculations to be made:

	Mean air temp.	Difference $T_b - T_o$	Degree days per day	Days in month	Degree days in month
January	1.2	23.8	23.8	31	738
February	2.9	22.1	22.1	28	619
March	4.7	20.3	20.3	31	629
April	8.3	16.7	16.7	30	501
May					
June					
July					
August					
Sept					
October	11.1	13.9	13.9	31	431
Nov	7.9	17.1	17.1	30	513
Dec	5.5	19.5	19.5	31	604
Total					4035

The total heat loss of the uninsulated roof is therefore:

$$\frac{1.54}{1000} \times 4035 \times 24 = 149.1 \text{ kWh per m}^2 \text{ for the year.}$$

8. The accuracy of degree days

There are three important considerations with regard to the accuracy of degree day data:

- the extent to which use of daily maximum and minimum temperatures is an acceptable approximation;
- errors due to an inappropriate choice of base temperature;
- how representative the weather monitoring station is of the region for which its data are normally published.

The importance of potential errors in degree day values depends on the particular use which is going to be made of them. It is important to know whether it is the absolute number of degree days which is important or their pattern of variation, irrespective of the accuracy of the absolute values.

8.1 Errors due to calculation method

From the detailed research that has been carried out, it has been found that there is no significant difference between the degree days obtained from hourly measured temperatures, and those obtained from a formula which uses measured daily maximum and minimum temperatures which assumes that the temperatures between these follow a sine wave pattern.

There is also no significant difference between the heating degree days obtained from hourly measured temperatures, and those obtained using the British Gas Method at degree day values above two degree days per day (or 60 degree days per month), which for 15.5°C base temperatures excludes only the central summer months. At levels below this, however, the British Gas Method seems to give a figure which is consistently high by up to one degree day per day. Cooling degree days would be in error in a similar way only in the deep winter months.

Therefore, for most applications, the errors due to the assumptions in the British Gas Method only affect degree day totals for short times of the year of little importance.

8.2 Errors due to base temperature selection

The accuracy of degree day values is important in applications in which the result depends absolutely on the number of degree days, such as when calculating the heat loss of buildings for the purpose of sizing the heating systems.

Since the absolute number of degree days in a given period depends on the base temperature, it is also important to ensure appropriate selection of the base temperature. For example, lowering the base temperature from 18.0°C to 15.5°C raises the total degree days in a year from 2,030 to 2,950 at Heathrow, an increase of 45%. Potentially this is by far the greatest source of error in any application of degree days.

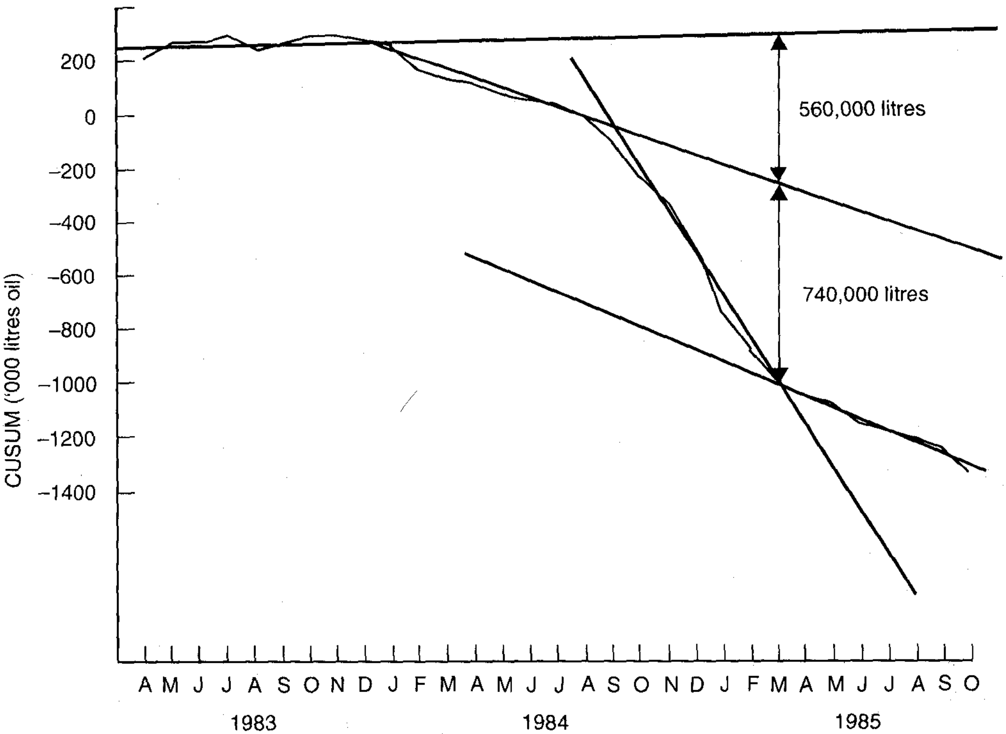


Fig 7 CUSUM for North Middlesex Hospital (Base 15.5°C)

The choice of base temperature also affects the outcome of CUSUM method calculations of savings. As the degree day values for individual months are different depending on the base temperature used, lowering the base temperature causes the graph of energy against degree days (Fig 4) to become steeper, with a higher intercept point. However, the differences in degree days between one base temperature and another are not consistent from month to month, and hence the distribution of points on the baseline graph will differ especially in the summer months when degree days are small. This difference is then reflected in the CUSUM graph, as can be seen by comparing Figs 6 and 7, which show the energy consumption for the North Middlesex Hospital using degree days to base 18.5°C and 15.5°C respectively.

The overall effect of changing the base temperature is minor differences of detail and shape of the CUSUM graph, indicating slightly different savings. In this example, the total savings between November 1983 and March 1985 were 13.4 million litres for 18.5°C base temperature and 13.0 million litres for 15.5°C, with the main difference being the way the savings are apportioned between the two measures.

Broadly speaking, providing 15.5°C is not far removed from the base temperature required (within 4 or 5°C), using published 15.5°C degree day data is adequate for the initial appraisal of energy savings using CUSUM. Most users will find them adequate to gain confidence in the method applied to most buildings, and the majority will find 15.5°C or 18.5°C degree days a satisfactory base temperature for a permanent energy monitoring programme if degree day data to another base temperature is not easily available.

8.3 Location of the observing station

The third area of concern regarding accuracy of degree days is the location of the observing station, and the extent to which it is properly representative of the region it serves. Degree days are regularly published for 18 regions. The data are calculated from the maximum and minimum temperatures measured at one observing station in each region. For historical reasons these are located either at airports or military establishments.

It is known that the local weather conditions can vary significantly from one location to another within even the same region. Fig 8 shows the pattern of variation of total annual degree days across the UK, together with the locations of the observing stations and the boundaries of each region. This indicates that there can be substantial variation in the absolute numbers of degree days within a region. The isopleths in Fig 8 are shown at intervals of roughly 300 degree days a year or 10% variation. On the one hand, there are quite large contiguous areas in the same isopleth interval which extend across adjacent regions, whilst within a region there can be significant differences in total degree days from one part to another.

In addition, Fig 8 shows that the observing stations at which the data are gathered are not normally within the major conurbations where the degree days are going to be used. For example, there is a difference of 5% between degree days at London Heathrow and those at Kew which are only seven miles apart, and 8% difference between Hurn (Bournemouth), the observing station in the Southern Region, and Southampton, the major location of buildings in the same region. Similar difficulties are encountered for cities in the Pennines served by observing stations at Ringway (to the west), Finningley (on low ground east of Doncaster) and Leeming (in the Swale Valley).

For the purpose of monitoring using the CUSUM method, the absolute values of degree days are less important than the pattern of variation. It is found that the pattern of variation is broadly the same for all regions in any one heating season, even though it can vary markedly from year to year. Fig 9 shows the variation of degree days for five of the standard region observing stations - Plymouth, Birmingham, Honington, Boulmer and Leuchars. These regions cover widely different temperature levels but reveal a fairly similar pattern of variation.

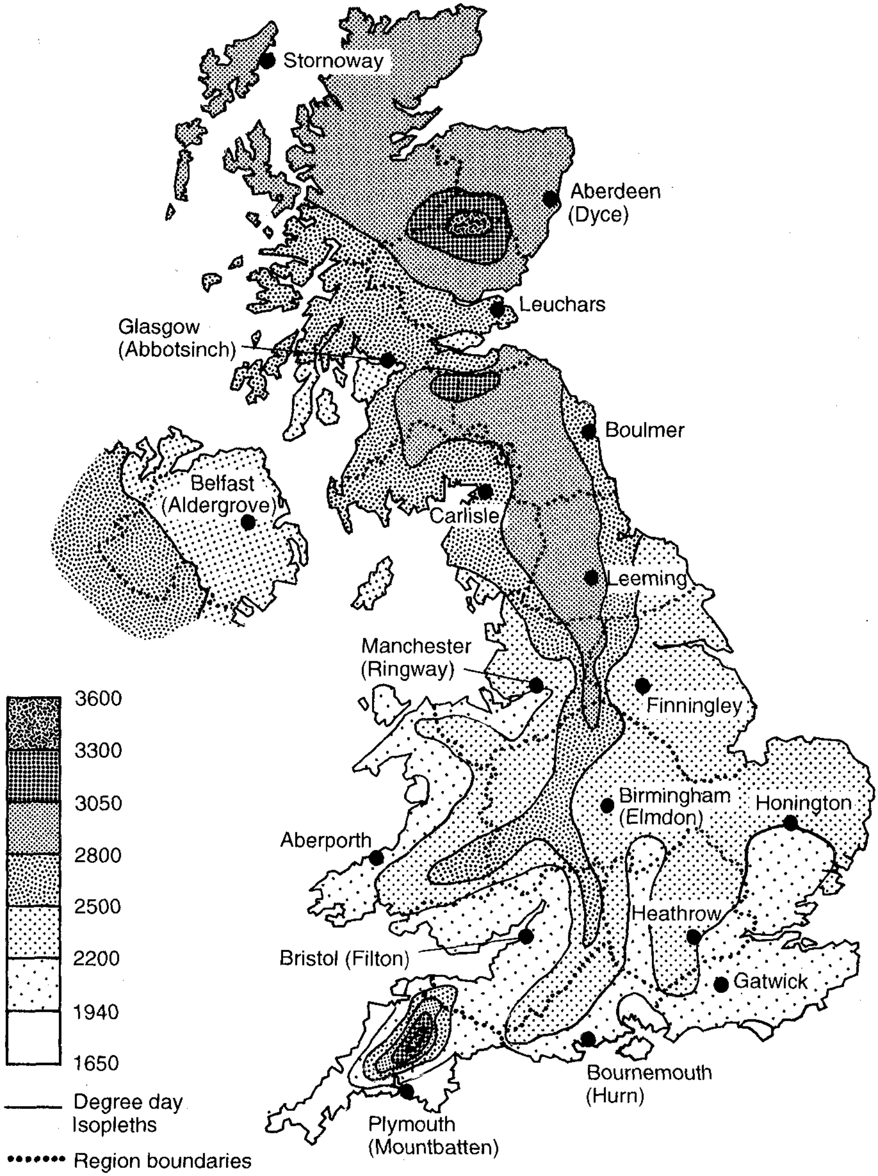


Fig 8 Degree day isopleths

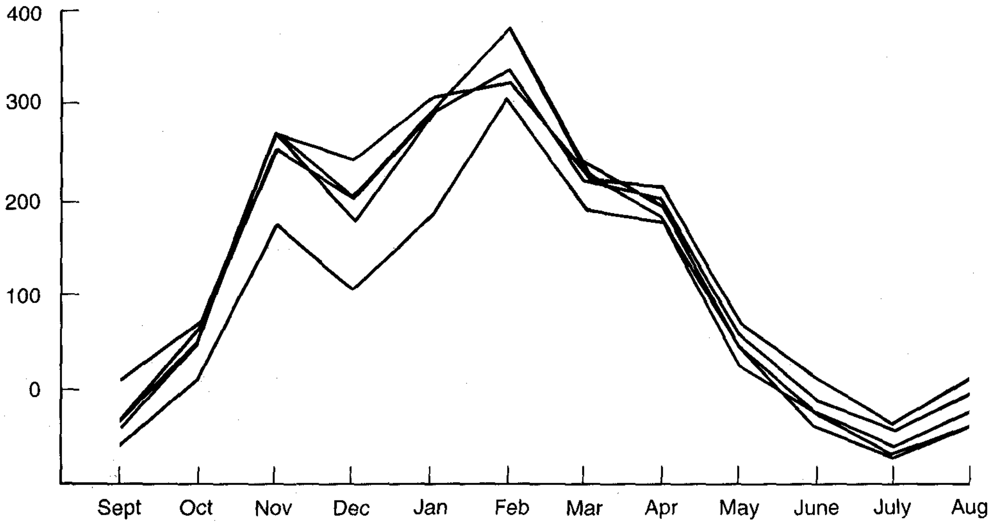


Fig 9 Variation of degree days for five centres 1985 - 1986

This means that since the pattern of variation is likely to be similar throughout the UK, proximity to the observing station is not a particularly important consideration for the purpose of monitoring. For most energy users, the published degree days data will be adequate to establish a monitoring scheme for buildings energy use and to evaluate the initial savings made. The need for more accurate degree day data can then be assessed in the light of these results.

For the design of building heating plant and heat loss calculations, it is much more important to ensure that the degree day data are for an appropriate observing station when calculating the absolute degree days for an area. Where local degree day data are not available, it is possible to determine the degree days for one year from the monthly mean temperatures using Hitchin's Formula, and to use data from the published regions to relate this known year to the 20 year average.

Example

The monthly mean temperatures for Sheffield over the period July 1984 to June 1985 are given in Appendix 3. Using Hitchin's Formula these can be used to calculate the local degree days for 1984-85 and to establish the difference between Sheffield and Finningley (East Pennines) in that year as a ratio, as shown in Table 10. From this it can be seen that degree days at Finningley were consistently higher (11 out of 12 months). It would be highly unusual if this pattern only appeared in this one season.

Comparing Finningley degree days for 1984-85 with the 20 year average shows that 1984-85 was not typical. It was milder (fewer degree days) in November, but colder from January to March. A best estimate for the 20 year average at Sheffield can be obtained by multiplying the 20 year average for Finningley by the ratio of degree days for the two sites in this one year.

Adjusting figures in this manner currently represents the only convenient way open to most users of degree days who only have published figures to work from.

Table 10 Estimation of average annual degree days by comparison of local mean air temperatures with data for a standard region										
		Monthly mean air temp in °C	15.5°C minus mean monthly air temp	Degree days per day (Hitchin's Formula)	Days in month	Monthly degree days	Degree days at Finningley	Ratio (A)	Twenty year average Finningley (B)	Sheffield twenty year average (A x B)
1984	July	17.2	-1.7	0.74	31	23	49	0.46	43	20
	August	17.5	-2.0	0.64	31	20	33	0.61	43	26
	September	13.5	2.0	2.64	30	79	77	1.03	79	81
	October	11.0	4.5	4.70	31	146	154	0.95	156	148
	November	7.7	7.8	7.74	30	232	238	0.97	280	272
	December	5.1	10.4	10.41	31	323	341	0.95	353	335
1985	January	1.5	14.0	14.00	31	434	448	0.97	370	359
	February	2.7	12.8	12.80	28	358	376	0.95	333	316
	March	5.0	10.5	10.51	31	326	340	0.96	306	294
	April	8.2	7.3	7.29	30	219	222	0.99	223	221
	May	10.6	4.9	4.81	31	149	160	0.93	143	133
	June	12.7	2.8	3.25	30	98	107	0.92	69	63

9. The effect of other factors on degree day calculations

The applications of degree days considered in this Booklet have been simplified by making a number of assumptions. These assumptions are reasonably valid for most buildings but in exceptional circumstances other factors need to be taken into account, the most important of which are wind and solar gain.

The total heat loss from a building is given by:

Heat loss = Fabric loss + ventilation loss

or

Heat loss = AU (T_{inside} - $T_{outside}$) + NVS (T_{inside} - $T_{outside}$)

or

Heat loss = (T_{inside} - $T_{outside}$) (AU + NVS)

where:

A = Area of fabric;
U = 'U'-value;
V = Volume;
S = Constant;
N = Ventilation rate.

A, U and V are fixed characteristics of the building, and S is a constant. The ventilation rate, N, however, will vary according to circumstances within the building at a particular time (windows open, doors closed, fans on/off, etc.) and outside wind conditions. Thus degree days may not be the only variable in some circumstances.

The value of N is usually significant even in a building with closed external doors and windows, because of gaps in the building fabric through which air moves under pressure. On a calm day, in a moderately well-sealed building where external doors and windows are closed, there would be about three air changes per hour. As the wind pressure increases, the ventilation rate rises. This will be a particularly important consideration in exposed areas, in built up areas with wind problems and in tall buildings. Ventilation rates of up to 25 air changes per hour have been recorded on the upper floors of buildings of only 10 storeys. In these circumstances, if under normal conditions fabric and ventilation losses are roughly equal, then wind effects could cause the degree day related component of heat loss to vary by a factor of over 20. In most buildings the ventilation rate cannot easily be measured, but it will add to the scatter in monitoring data.

Solar gain is important where heat inputs to a building through captured sunlight are large compared with the rate of heat loss. This affect occurs in buildings with a high glazed area and

low fabric loss. The orientation of a building is also important; solar gain will be more significant in building with a mainly southerly aspect. The way the building is affected depends on individual circumstances - how the building heating and ventilation is controlled, the activities of occupants and so on. The CIBSE Guide contains detailed analysis of solar gain effects.

10. Sources of degree day information

10.1 'Energy Management'

Degree day values to base 15.5°C for 18 standard regions are published every other month in the Energy Efficiency Office's journal 'Energy Management'. Degree day values are given for the current year and the immediate past year, together with the 20 year average. Due to publishing schedules, the information provided is usually two to three months behind the current date. More up-to-date information may be obtained from other sources (see Section 10.2). Appendix 4 contains the degree days published in 'Energy Management' from 1983 - 93. For details on how to obtain copies of 'Energy Management' see Section 11.

10.2 Other sources and measuring your own degree days

Although the published degree day tables only cover the 18 standard regions, data is available for many more locations. The Meteorological Office's Degree Day Service provides information for over one hundred locations - historic, on-going or forecast values for a variety of base temperatures (heating or cooling).

This service can be provided usually within a few days after the end of a calendar month. The service can also provide degree days on a daily, weekly or monthly basis. Other weather data can be provided for up to 600 locations in the UK and many more overseas.

For more details contact:

The Degree Day Product Manager
Room G/11
The Meteorological Office
Sutton House
London Road
Bracknell
Berks RG12 2SZ

Tel No: 0344 856567
Fax No: 0344 854475

Heating and cooling degree day figures to a variety of base temperatures for a choice of over 40 UK centres can also be obtained every month from Vilnis Vesma. For more information contact:

Vilnis Vesma
17 Church Street
Newent
Glos GL18 1PU

Tel No: 0531 821350
Fax No: 0531 820603

This firm can also assist with methods of local degree day measurement based on PC software with manual or automatic temperature recording and entry.

Several building energy management systems also include a facility which enable degree days to be recorded.

11. Sources of further reading and information

- ***General reference material***

  CIBSE Guide 1987, Chartered Institution of Building Services Engineers, for more detailed coverage of heat loss calculations in particular.

  Estimating monthly degree days, E.R. Hitchin, Building Services Engineering Research and Technology 4 (4) 159-162 (1983).

'U' values, Eurisol-UK.

Degree days in Britain, E.R. Hitchin, Building Services Engineering Research and Technology 2 (2) 73-82 (1981).

- ***The latest news in energy efficiency technology***

'Energy Management' is a free journal issued on behalf of the EEO which contains information on the latest developments in energy efficiency, and details of forthcoming events to promote their implementation. It also contains information addresses and contact names for the Regional Energy Efficiency Offices (REEOs).

Copies of 'Energy Management' can be obtained through:

Maclean Hunter Limited
Maclean Hunter House
Chalk Lane
Cockfosters Road
Barnet
Hertfordshire
EN4 0BU

12. Acknowledgements

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Appendix 1

Factors for conversion of fuel prices to pence per kWh (gross calorific value)

Fuel	From	To p/kWh multiply by
Electricity	p/kWh	1.000
Natural gas	p/therm	0.0341
Gas oil (Class D)	p/litre	0.0936
Light fuel oil (Class E)	p/litre	0.0885
Medium fuel oil (Class F)	p/litre	0.0868
Heavy fuel oil (Class G)	p/litre	0.0866
Propane	£/tonne	0.00720
Butane	£/tonne	0.00730
Coal *	£/tonne	0.0128

* Assumes calorific value of 28 GJ/tonne.

Appendix 2

Establishing the formula of a straight line graph

A relationship such as (Fig 5):

Energy = 920 x degree days + 130,000

has the form:

$$y = mx + c$$

where y represents energy and x represents degree days. The values m and c are constants which need to be obtained from the graph plotting energy use against degree days.

Procedure

Plot energy as the y-axis and degree days as the x-axis. The values of m and c are then obtained from the plotted graph, as shown in Fig 10.

- *c* is the intercept point on the y-axis, i.e. the energy value when the degree days are zero.
- *m* is the gradient or slope of the best fit line on the graph. The value is obtained by selecting two convenient values of x (x_1 and x_2 on Fig 10) and drawing lines from these points up to meet the best-fit line, and then across to the y-axis (y_1 and y_2 on Fig 10). The value of m can now be calculated from:

$$m = \frac{y_2 - y_1}{x_2 - x_1}$$

To ensure the highest accuracy, x_1 and x_2 should be as far apart as possible. Often zero is selected for x_1, simplifying the formula to:

$$m = \frac{y_2 - c}{x_2}$$

To calculate m and c more accurately, the least square best fit statistical calculation gives:

$$m = \frac{N\,\Sigma xy - \Sigma x\,\Sigma y}{N\,\Sigma(x^2) - (\Sigma x)^2}$$

and

$$c = \frac{\Sigma y\,\Sigma(x^2) - \Sigma xy\,\Sigma x}{N\,\Sigma(x^2) - (\Sigma x)^2}$$

for N data points where Σ means the sum of all such terms. This calculation is available as a standard function on many scientific calculators.

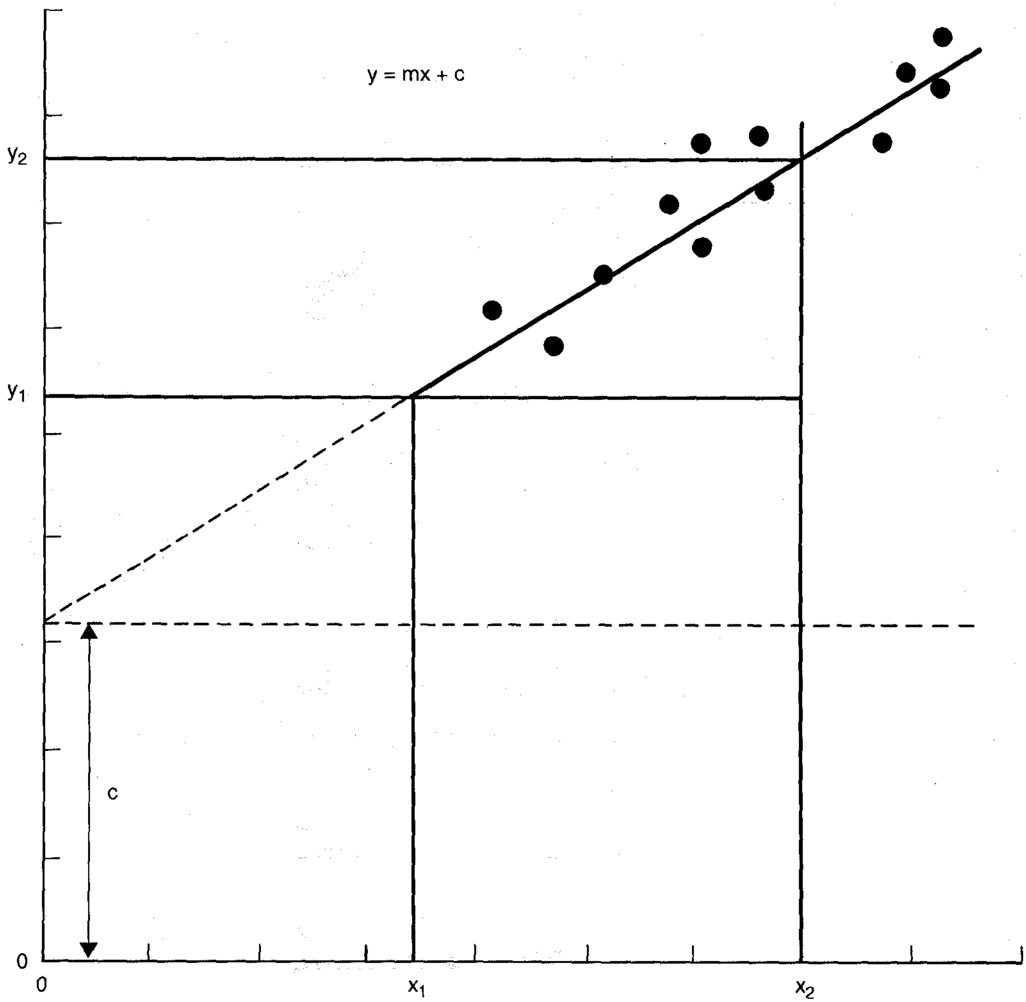

Fig 10 Obtaining the formula of a straight line graph

DEGREE DAYS TO BASE 15.5°C 1983-1993											
South Eastern											
	1983-84	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93	20 year average
April	257	245	202	277	169	217	252	227	225	209	231
May	160	174	135	141	159	108	90	144	164	90	146
June	52	64	81	64	80	62	74	77	96	52	74
July	17	41	29	30	32	43	21	41	20	24	36
August	32	26	49	61	48	43	36	24	26	33	42
September	67	74	62	132	69	72	45	92	64	70	79
October	168	138	142	130	156	132	106	112	172	229	160
November	241	203	344	227	263	306	280	246	267	232	265
December	323	321	265	300	299	259	295	347	359	358	321
January	348	468	368	467	306	311	281	351	358	288	360
February	338	376	467	331	316	271	210	402	309	316	331
March	323	346	332	346	267	238	233	225	252	290	293
TOTAL	2326	2476	2476	2506	2164	2062	1923	2288	2312	2191	2338

DEGREE DAYS TO BASE 15.5°C 1983-1993											
Southern											
	1983-84	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93	20 year average
April	253	238	209	288	192	224	264	229	229	207	229
May	155	165	134	152	153	112	105	144	145	100	144
June	50	66	84	71	85	63	81	80	94	61	74
July	19	50	42	39	38	41	29	48	28	28	38
August	37	34	42	65	55	49	44	33	33	34	43
September	65	67	66	143	70	75	62	102	67	59	80
October	156	135	150	138	163	131	111	114	166	233	153
November	236	218	341	224	260	293	251	243	260	217	252
December	293	316	262	288	290	252	301	343	325	353	305
January	332	467	356	446	294	289	254	351	370	274	343
February	323	354	448	324	310	260	200	391	299	293	316
March	323	339	322	328	259	233	238	236	247	293	286
TOTAL	2242	2449	2456	2506	2169	2022	1940	2314	2263	2152	2263

DEGREE DAYS TO BASE 15.5°C 1983-1993

South Western

	1983-84	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93	20 year average
April	227	190	188	268	164	196	242	195	201	195	205
May	150	141	116	142	140	107	74	131	108	96	129
June	50	48	67	60	87	43	53	58	87	39	64
July	7	25	23	29	23	35	7	24	24	18	27
August	16	14	33	63	27	34	18	12	21	26	28
September	43	48	43	107	49	56	36	60	35	61	57
October	126	106	113	102	132	101	76	78	140	194	118
November	176	195	273	193	211	219	184	201	219	188	205
December	234	250	205	232	242	189	239	280	262	290	248
January	289	385	282	385	242	240	218	308	323	240	289
February	281	280	407	283	273	219	177	338	271	253	272
March	294	287	290	292	238	212	200	214	232	250	256
TOTAL	1893	1969	2040	2156	1828	1651	1524	1899	1923	1850	1898

DEGREE DAYS TO BASE 15.5°C 1983-1993

Severn Valley

	1983-84	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93	20 year average
April	227	183	180	265	133	182	230	196	193	178	196
May	136	139	117	121	127	88	62	126	108	75	111
June	35	38	70	46	59	40	48	47	80	26	53
July	4	14	18	18	15	33	5	20	10	10	25
August	9	7	29	48	19	27	14	8	10	21	29
September	45	44	36	95	44	47	30	47	34	48	52
October	127	96	123	109	143	111	87	84	134	193	129
November	201	199	287	193	224	253	224	221	226	195	228
December	257	270	237	238	267	205	280	310	301	320	287
January	314	409	324	411	271	249	233	332	334	252	318
February	312	335	432	293	271	226	190	344	263	267	300
March	296	295	292	311	239	209	194	196	219	239	252
TOTAL	1963	2029	2145	2148	1812	1670	1597	1931	1912	1824	1980

DEGREE DAYS TO BASE 15.5°C 1983-1993

Midland

	1983-84	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93	20 year average
April	270	240	222	296	176	235	277	241	235	208	241
May	176	189	166	142	181	134	115	158	152	103	160
June	68	67	105	77	105	72	88	75	114	49	87
July	21	45	37	40	45	52	27	44	25	37	43
August	36	34	52	78	51	54	40	24	33	47	48
September	79	79	64	150	86	88	64	88	76	81	89
October	176	149	162	164	200	172	132	122	175	252	177
November	250	239	352	249	284	334	295	266	277	257	278
December	322	340	298	301	321	252	335	355	357	391	336
January	374	467	386	475	325	301	286	395	383	308	373
February	368	407	482	339	316	277	227	400	296	310	340
March	346	344	335	362	284	257	217	240	253	283	306
TOTAL	2486	2600	2661	2673	2374	2228	2103	2408	2376	2326	2478

DEGREE DAYS TO BASE 15.5°C 1983-1993

West Pennines

	1983-84	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93	20 year average
April	267	216	216	286	165	210	274	233	224	210	231
May	161	158	139	130	168	122	110	140	147	100	143
June	65	68	98	66	103	58	81	76	119	42	79
July	14	33	29	42	32	51	23	41	19	33	37
August	26	24	48	78	45	52	41	28	31	49	40
September	76	79	51	130	83	94	65	105	72	81	84
October	167	141	146	154	182	162	128	129	164	247	164
November	237	229	344	241	266	309	273	267	267	257	269
December	297	315	290	292	295	260	351	360	318	385	325
January	370	447	376	438	317	285	281	396	376	311	360
February	342	353	437	324	316	269	233	376	284	298	325
March	330	335	322	345	297	262	230	236	254	273	295
TOTAL	2352	2398	2496	2526	2269	2134	2090	2387	2275	2286	2352

DEGREE DAYS TO BASE 15.5°C 1983-1993

North Western

	1983-84	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93	20 year average
April	284	234	229	300	199	229	266	253	235	229	248
May	175	183	157	156	195	145	134	162	154	125	167
June	87	79	116	88	113	60	96	85	122	52	95
July	25	44	52	56	45	56	33	51	23	49	51
August	49	36	62	97	53	53	39	36	33	56	59
September	97	95	78	150	97	106	76	123	96	103	104
October	184	153	155	164	206	165	117	147	197	275	184
November	258	236	374	236	278	306	289	287	283	263	285
December	303	311	301	311	315	256	411	354	337	375	339
January	292	450	392	464	323	260	276	380	375	316	371
February	332	356	434	336	308	266	251	373	296	291	335
March	327	342	322	352	309	276	244	266	283	292	311
TOTAL	2413	2519	2672	2710	2441	2178	2232	2517	2434	2426	2549

DEGREE DAYS TO BASE 15.5°C 1983-1993

Borders

	1983-84	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93	20 year average
April	307	280	251	320	228	259	291	249	253	233	268
May	238	241	200	171	223	189	166	201	176	163	200
June	113	114	138	116	153	98	117	107	136	76	118
July	36	56	66	58	63	63	41	67	40	56	64
August	48	47	73	106	69	62	51	34	38	68	63
September	100	99	90	132	108	99	91	115	94	115	105
October	184	161	146	171	216	178	142	158	178	252	177
November	259	235	349	248	267	292	260	255	288	275	271
December	306	326	324	328	284	249	343	335	329	372	336
January	397	409	387	418	343	273	304	390	341	330	371
February	345	349	414	333	318	280	257	357	291	276	336
March	335	348	341	359	316	290	224	270	270	295	311
TOTAL	2668	2665	2779	2760	2588	2332	2287	2538	2434	2511	2620

DEGREE DAYS TO BASE 15.5°C 1983-1993											
North Eastern											
	1983-84	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93	20 year average
April	286	243	223	305	186	224	280	240	235	208	246
May	191	200	172	138	189	152	121	163	159	119	166
June	82	78	114	78	113	64	88	79	120	55	89
July	22	43	42	46	40	48	26	43	26	40	44
August	38	36	55	58	48	46	38	23	28	51	48
September	88	85	68	137	86	89	72	94	80	91	91
October	16	151	160	165	210	172	131	136	169	253	175
November	257	239	371	237	272	326	280	269	279	265	283
December	313	347	323	309	310	249	358	336	352	387	333
January	399	458	399	460	349	288	289	410	389	323	379
February	361	375	457	344	314	271	235	379	287	286	340
March	340	345	339	359	298	265	218	252	261	288	307
TOTAL	2393	2600	2723	2636	2415	2194	2136	2424	2385	2366	2501

DEGREE DAYS TO BASE 15.5°C 1983-1993											
East Pennines											
	1983-84	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93	20 year average
April	275	243	222	296	181	229	278	235	226	204	236
May	184	189	160	136	179	145	122	152	147	106	155
June	86	74	107	77	108	69	88	81	116	41	84
July	25	49	38	43	38	48	29	45	24	38	43
August	34	33	56	54	48	44	40	25	32	48	45
September	84	77	65	138	87	91	52	87	77	88	85
October	168	154	146	175	205	166	127	120	160	244	171
November	247	238	354	248	272	317	289	255	276	265	275
December	319	341	302	301	306	257	339	341	337	394	338
January	395	448	391	448	329	291	292	404	384	324	371
February	358	376	463	335	311	270	235	385	288	298	338
March	337	340	328	354	290	252	218	238	249	290	296
TOTAL	2512	2562	2632	2605	2354	2179	2109	2368	2316	2340	2437

DEGREE DAYS TO BASE 15.5°C 1983-1993

East Anglia

	1983-84	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93	20 year average
April	255	252	214	280	171	226	276	233	235	209	236
May	161	196	159	123	178	119	113	145	171	98	149
June	61	77	99	75	90	75	85	79	99	48	77
July	21	45	33	34	37	48	24	42	21	25	39
August	28	29	49	62	42	43	33	22	24	32	39
September	60	75	62	127	64	76	43	93	68	69	74
October	157	123	151	143	157	146	107	106	168	237	157
November	244	213	364	234	269	325	282	270	271	260	272
December	320	324	275	308	302	290	323	350	361	377	332
January	377	488	387	480	319	316	280	373	370	313	370
February	357	396	478	339	320	280	222	411	301	319	339
March	340	345	328	373	300	245	223	240	256	282	296
TOTAL	2381	2563	2599	2578	2249	2189	2011	2364	2345	2269	2380

DEGREE DAYS TO BASE 15.5°C 1983-1993

West Scotland

	1983-84	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93	20 year average
April	293	223	234	304	217	237	280	249	232	236	246
May	182	159	163	164	182	158	152	166	140	131	166
June	100	72	122	101	122	62	105	92	127	54	97
July	37	46	62	71	50	62	45	54	28	62	55
August	45	44	88	104	74	62	59	47	38	75	63
September	122	114	112	153	113	106	115	126	112	117	115
October	200	185	182	183	240	198	152	159	205	296	195
November	267	262	386	254	282	308	309	312	295	293	299
December	309	325	320	338	347	251	421	358	340	369	350
January	426	468	411	455	362	257	300	397	362	327	378
February	330	364	436	351	320	291	260	387	293	265	340
March	328	352	327	361	324	308	243	278	275	294	315
TOTAL	2639	2614	2843	2839	2633	2300	2441	2625	2447	2519	2619

DEGREE DAYS TO BASE 15.5°C 1983-1993

East Scotland

	1983-84	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93	20 year average
April	302	263	247	313	222	248	281	249	249	235	259
May	222	213	188	170	198	182	143	190	155	154	190
June	114	88	133	111	144	85	110	97	141	68	109
July	37	44	65	64	61	65	42	64	38	68	60
August	38	49	83	114	69	67	57	48	44	86	65
September	116	112	110	145	120	103	110	125	114	123	113
October	197	190	167	185	236	199	156	166	193	282	195
November	278	257	376	267	282	314	284	291	296	311	296
December	321	332	343	350	326	272	401	368	362	399	354
January	436	439	405	436	369	276	321	425	383	353	386
February	347	349	422	353	328	293	274	366	312	269	344
March	348	355	325	360	319	301	234	296	288	303	319
TOTAL	2756	2691	2864	2868	2674	2405	2413	2685	2575	2651	2690

DEGREE DAYS TO BASE 15.5°C 1983-1993

North East Scotland

	1983-84	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93	20 year average
April	314	258	266	321	216	262	300	252	259	250	272
May	231	218	203	171	213	184	167	199	175	154	200
June	129	102	143	115	165	88	118	114	146	78	119
July	46	53	65	71	68	67	47	72	43	71	68
August	48	62	87	120	77	73	70	46	47	96	74
September	127	140	128	141	127	112	112	135	121	130	128
October	201	209	191	195	244	203	181	187	201	286	207
November	277	260	391	276	309	293	282	288	297	307	304
December	311	321	366	364	336	271	391	353	356	398	359
January	466	439	411	434	382	276	332	411	366	353	395
February	352	347	448	351	338	299	284	380	317	275	352
March	360	358	352	377	343	305	245	301	292	309	332
TOTAL	2862	2767	3051	2936	2818	2433	2529	2738	2620	2707	2810

DEGREE DAYS TO BASE 15.5°C 1983-1993

Wales

	1983-84	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93	20 year average
April	277	211	221	311	173	222	272	240	232	219	239
May	188	193	169	166	181	149	124	165	168	110	166
June	83	88	123	83	117	71	89	87	119	60	94
July	22	41	56	56	43	71	28	36	30	35	47
August	27	26	72	89	44	60	32	21	27	60	44
September	72	75	60	130	74	87	63	81	54	89	78
October	152	141	150	136	179	144	118	111	163	214	149
November	219	223	302	226	244	257	230	239	240	220	237
December	262	289	270	268	288	223	316	321	300	330	285
January	328	407	335	415	301	272	266	369	336	284	331
February	316	326	439	318	303	261	232	362	262	280	308
March	337	329	321	336	270	261	236	249	257	277	296
TOTAL	2283	2349	2518	2534	2217	2078	2006	2281	2188	2178	2274

DEGREE DAYS TO BASE 15.5°C 1983-1993

Northern Ireland

	1983-84	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93	20 year average
April	296	219	222	307	194	207	284	243	235	234	241
May	184	179	176	166	174	150	145	167	148	128	167
June	88	70	109	84	127	66	86	87	121	57	93
July	29	43	53	56	44	62	32	46	25	53	49
August	29	39	77	110	59	65	52	35	34	73	57
September	95	106	74	139	107	106	100	114	93	124	103
October	179	177	155	120	227	173	145	148	189	265	181
November	244	281	343	265	264	290	276	279	284	276	282
December	281	320	312	322	298	257	353	359	305	368	327
January	404	456	384	391	344	278	306	384	344	329	361
February	323	326	402	328	325	284	283	364	299	268	323
March	337	339	325	338	295	284	234	261	272	288	305
TOTAL	2489	2555	2632	2626	2458	2222	2296	2487	2349	2463	2489

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